CHEMICAL FERTILISERS:
CONNECTING CHEMISTRY LABS TO PLANT LIFE

Jaya Ayyer

Growing sufficient quantities of the various crops needed to feed an ever-increasing population is a challenge faced by many countries - particularly, developing and under-developed countries. The availability of fertile land, suitable climatic conditions, and good agricultural practices; combined with a variety of inputs such as high yielding seeds, fertilizers, pest control agents, irrigation etc., play vital roles in this respect. This article aims to give readers an introduction to chemical fertilisers, one of the most important external inputs in food production.

Humans and other animals depend, directly or indirectly, upon plants to meet all their nutritional requirements. These nutritional requirements include not just carbohydrates, proteins, and vitamins, but also a variety of minerals, including phosphorous, potassium, iron, magnesium etc. Plants, too, have similar nutritional requirements. The carbohydrate (carbon, hydrogen and oxygen) needs of plants are met through light, air and water, through the process of photosynthesis. But, in addition to carbohydrates, plants also need elements like nitrogen (N) and sulphur (S) to produce amino acids; phosphorous (P) to synthesise nucleic acids; potassium (K) for ion transport and enzyme function, etc. These elements are absorbed by plants from the soil that they grow on.

Fertile soils are rich in these essential nutrients, allowing healthy growth of plants. However, farming of food crops often involves many successive cycles of large scale growth of plants in the same soil, without allowing the soil to regenerate. Over time, this leads to depletion of all the essential nutrients that the food crops seek for their growth.

Fertilisers are all those substances that can be used to add nutrients to soil, improving soil fertility, and increasing crop growth and yields. Fertilisers fall into two broad categories. Natural or organic fertilisers include peat, animal waste, composted wastes of plants, household waste, sewage sludge, bio-fertilisers etc. Chemical fertilisers are synthetically produced, and include chemicals such as urea, calcium ammonium nitrate, ammonium sulphate etc.

This article focusses on chemical fertilisers, providing insights into different aspects of this topic, generally unavailable in textbooks.

Nutrient needs of plants and their supply

For plants to grow and thrive, a number of chemical elements are needed. These can be classified as:

a. Macro or Major Nutrient elements – Nitrogen (N), Phosphorous (P) and Potassium (K)

b. Secondary Nutrients – Calcium, Magnesium and Sulphur

c. Micronutrients – Iron, Manganese, Zinc, and Copper, along with a number of other elements like Boron and Molybdenum at trace levels.

How are these supplied to the plants so that they can be absorbed?

The above elements have to be supplied in a chemical form to the soil (though some are sprayed on the leaves). They have to be water soluble, or must dissolve slowly over a period of time. The dissolved salts (in their ionic form) are absorbed by the roots' membranes, through osmosis. The microbial system of the soil plays an important part in converting some of the applied fertilisers into absorbable forms through enzymatic processes. Microbes also fix some of the excess nutrients in the soil. Hence, effective absorption of chemical fertilisers by plants depends on the microbial activity and water content of the soil in which they grow.

Chemical fertilisers can be produced in single nutrient or multi-nutrient chemicals forms. Single nutrient fertilisers are called 'Straight Fertilisers', and multi-nutrient ones are called 'Complex Fertilisers'. Except urea, most fertilisers are multi-nutrient ones. This is because fertilisers are inorganic water soluble chemicals, which have cations and anions, each contributing a nutrient.

Complex fertilisers contain two or more nutrients, and their composition is expressed in the order N-P-K. The N content is given as % Nitrogen (N) by weight (wt.), Phosphorus (P) content is expressed as P_2O_5 by wt. and potassium (K) content as K_2O by wt. in the dry form of the fertiliser. Both P_2O_5 and K_2O are conceptual representations by convention; they are not present in these chemical forms. The Sulphur content, as S, is also mentioned in N-P-K-S complex fertilisers.

We will now take a look at chemical fertilisers available in Indian markets.

Nitrogenous fertilisers

i. Urea: The most well-known and popular fertiliser in this category is **Urea.** This is a water soluble organic chemical, manufactured from ammonia (NH_3) and carbon dioxide (CO_2) through a high pressure and temperature process. The chemical formula of urea is NH_2-CO-NH_2. Urea contains about 46% nitrogen by weight.

Very large scale production of urea from ammonia (made through the Haber Bosch Process from N and H) and CO_2, has made it possible for farmers to obtain this most common nitrogenous fertiliser at low costs (further subsidised by Government in India). Urea is obtained as prills, through a process known as prilling, in which the molten urea is sprayed from a very tall tower down and as the droplets fall, they get solidified. Urea is completely water soluble, but is not directly absorbed by the plants. It is hydrolysed by an enzyme called Urease in soil microbes to ammonium and carbonate ions. Ammonium is absorbed by plants through osmosis.

Prill Tower

One may ask why ammonia cannot be supplied directly to the plants. It can be supplied, and in countries like the US, this is accomplished through pipelines that transport ammonia directly to farms. However, in its pure form at

room temperature, ammonia is a highly pungent and toxic gas. To avoid any harmful effects, ammonia is converted to urea, an easily transportable, water soluble and easily-applicable form for farmers.

Fig. 1. Urea Prills

ii. Calcium Ammonium Nitrate (CAN): This is a mixture of ammonium nitrate and calcium carbonate, granulated together to get a total nitrogen content of about 25% by weight, of which 12.5% is ammoniacal nitrogen (NH_4 form) and the other 12.5% is nitrate nitrogen (NO_3 form). As this contains the additional nutrient calcium, it is beneficial for crops, although its total nitrogen content is less than in urea.

iii. Ammonium Sulphate: This is often obtained as a by-product, and contains 20.6% N in ammoniacal form. As it also contains Sulphur (23% by wt.), a very important plant nutrient, ammonium sulphate is a good fertiliser for a number of crops. Being 100% water soluble, this is useful for drip irrigation, where the fertiliser solution is directly applied as a dilute solution to the plant root system through pipes; and sprinkler irrigation, where the solution is sprayed on the plant.

Phosphatic fertilisers

Phosphatic fertilisers contain phosphorous (represented as P_2O_5) as the major nutrient.

Phosphorous is naturally obtained through rock phosphate, which is a mineral rich in phosphorous, and mainly contains Calcium phosphate. This is the primary source of all phosphatic fertilisers. Rock phosphate is digested with mineral acids to get phosphoric acid, along with the calcium salt of the mineral acid. For example, reaction of rock phosphate with sulphuric acid gives phosphoric acid and calcium sulphate, known as phospho-gypsum, a by-product. The phosphoric acid is neutralised with ammonia and granulated to get Diammonium Phosphate (DAP), a very popular P fertiliser.

Fig 2. Rock Phosphate after coarse grinding and sizing

The reaction of rock phosphate with nitric acid generates phosphoric acid with calcium nitrate. The phosphoric acid - calcium nitrate mixture is neutralised with ammonia and granulated to get Ammonium Nitrophosphate (ANP) fertiliser.

The process involves acidifying phosphate rock with nitric acid to produce a mixture of phosphoric acid and calcium nitrate.

$$Ca_3(PO_4)_2 + 6\ HNO_3 + 12\ H_2O \rightarrow 2H_3PO_4 + 3\ Ca(NO_3)_2 + 12\ H_2O$$

The mixture is cooled to below 0°C, where the calcium nitrate crystallises, and can be separated from the phosphoric acid.

$$2\ H_3PO_4 + 3\ Ca(NO_3)_2 + 12\ H_2O \rightarrow 2H_3PO_4 + 3\ Ca(NO_3)_2{\cdot}4H_2O$$

The resulting calcium nitrate can be used as nitrogen fertiliser. When used in a reaction with ammonium carbonate, it results in the production of ammonium nitrate, and calcium carbonate - a by-product. The fertiliser calcium ammonium nitrate (CAN) is produced by granulating a mixture of ammonium nitrate and calcium carbonate. The filtrate is composed mainly of phosphoric acid with some nitric acid and residual calcium nitrate, and this is neutralized with ammonia to produce Ammonium Nitrophosphate (ANP).

$$Ca(NO_3)_2 + 4\ H_3PO_4 + 8\ NH_3 \rightarrow CaHPO_4 + 2\ NH_4NO_3 + 3(NH_4)2HPO_4$$

Major Phosphatic Fertilisers are:

1. Single Superphosphate
2. Triple Superphosphate

3. Monoammonium Phosphate, MAP (11-52-0)

4. Diammonium Phosphate, DAP (18-46-0)

5. Ammonium Nitrophosphate, ANP (20-20-0)

Potassium fertilisers

The third most important plant nutrient is potassium (K). This is supplied as Potassium Chloride (Muriate of Potash, MOP), or as Potassium Sulphate. MOP is cheaper in value, and is extensively used by farmers as the K fertiliser. It is used as such, or in combination with N and P as complex fertilisers.

Complex fertilisers

These contain more than one major nutrient and are denoted as N-P-K-S. Some of the phosphatic fertilisers mentioned above come under this category as they contain N also. N-P-K complex fertilisers are extensively used by farmers. These incorporate MOP (KCl) or potassium sulphate, to get the K content.

Liquid fertilisers and water soluble fertilisers

Liquid fertilisers like Urea Ammonium Nitrate, and 100% water soluble fertilisers with multiple nutrients, have been approved by Government of India for manufacture and sale. These are used in drip irrigation and spray application. Many companies have been producing and marketing these. However, these are mainly used in horticulture and high-value crop production, due to their relatively high costs.

Micronutrient fertilisers

Although plants do not need micronutrients in large quantities like N,P,K etc., these are essential for healthy growth and production of crops by the plants. These are provided in the form of water soluble chemical salts, such as Zinc Sulphate, Manganese Sulphate, Copper Sulphate, Borax, Ferrous Sulphate, Magnesium Sulphate and Ammonium Molybdate. Chelated (EDTA) salts are added to enable easy absorption by plants.

Controlled release fertilisers

To prevent losses of fertilisers through leaching and other mechanisms, as well as to minimise multiple applications, several controlled release fertilisers have been developed. To regulate the release of nutrients slowly and over a period of time, highly water soluble fertilisers are coated with a layer of water insoluble, but soil friendly materials.

i. Sulphur coated urea (molten sulphur is coated on urea granules), SCU, was developed by International Fertiliser Development Corporation (IFDC), USA.

ii. Phospho-gypsum coated urea (GCU) was developed by the research team at Gujarat Narmada Valley Fertilisers Company in Gujarat.

iii. Urea Supergranules (USG) is another controlled-release urea fertiliser used in social forestry. Such controlled release fertilisers have shown improved nutrient use efficiency (NUE) during agronomic trials. However, their commercial use is limited, due to their high costs and low availability.

Fertiliser production in India

As per the data published by Ministry of Chemicals & Fertilisers, the following are the quantity of production of major fertilisers in India.[1]

As the indigenous production of fertilisers is not sufficient to meet the country's requirements, additional quantities are imported.

Table 1: Production of Major Fertilisers in India (Qty. in Lakh MT)

Fertiliser / Year	2006-07	2007-08	2008-09	2009-10
Urea	203.1	198.6	199.2	211.3
DAP	48.52	42.12	29.93	42.47
Complex Fertilisers	74.28	58.72	67.99	80.38

Quality and specifications of chemical fertilisers[2]

Both the specifications and quality of the chemical fertilisers sold in Indian markets are strictly controlled by Government of India. The composition, detailed specifications and the analysis procedures for each component are specified under Fertiliser (Control) Order 1985. This order is revised periodically to incorporate any changes needed, new additions to the list etc. Manufacturers have to adhere to these without any deviation. Spot quality checks are done by Government agencies in the market, and legal actions are taken against the manufacturer if the specified quality is not met. In addition to nutrient content; moisture content, size, and water solubility etc. are also strictly specified and enforced.

Administered prices of fertilisers

To ensure adequate availability of fertilisers throughout the country at affordable prices to farmers, the Indian government (Department of Fertilisers) has formulated the Fertiliser Pricing Policy. According to this policy, the selling price of major fertilisers is fixed by the government, and revised at regular intervals. The difference between costs of production (plus adequate profits) and the selling price is compensated to the manufacturing companies using certain complex formulae. This current practice of reimbursing fertiliser manufacturing companies, is called fertiliser subsidy. This mechanism is being critically examined for replacement with other methods, like direct cash subsidy to the farmers.

Application of Chemical Fertilisers[3]

Most natural fertilisers are applied directly to the soil or root system of the plants, as these are also soil conditioners. However, chemical fertilisers can be applied in multiple ways, depending on the type of crop, water availability, absorption pattern etc. Some of these application modes are mentioned here:

A. Solid chemical fertilisers

- Basal Application: A fertiliser is directly applied to the soil, and spread throughout the cropping area before sowing seeds, and periodically during crop growth. Nutrient losses are high in this case, as the solid can easily move away from the root system. To compensate for this, often, higher than required quantities are applied. Highly soluble fertilisers like urea can get leached away too. Ammonia, formed by hydrolysis of urea, also evaporates into the atmosphere.
- Application near the root system, on the surface or deeper into the soil: This is a better method as compared to basal application. However, it is more labour intensive. Use of seed-cum-fertiliser drills is beneficial for this.
- Placement in bands near rows of plants.

B. Liquid Fertilisers, Water Soluble fertilisers and Micronutrient Solutions

- Foliar application: A dilute solution of the fertiliser in water is sprayed on the plants. Nutrients are absorbed directly, by leaves.
- Through irrigation water: Water soluble fertilisers are applied through water channels.

Advantages and disadvantages of use of chemical fertilisers

For a country like India with a population of 1.3 billion people, production of sufficient quantities of food is a major challenge. From a famine affected country in the 1960's, we have managed to come close to becoming self-sufficient in food grains today, through the concerted efforts of scientists, farmers and successive governments. This has largely been possible through the use of high yielding varieties of seeds, irrigation, the use of chemical fertilisers and other agrochemicals, like insecticides, pesticides etc. Therefore, the role of chemical fertilisers cannot be undermined in achieving our current food security.

However, the indiscriminate use of chemical fertilisers can have many negative effects on the soil system, as well as on the larger environment. A balanced supply of all nutrients needed for each crop (this varies from crop to crop), along with micronutrients and soil conditioners, can ensure sustained agricultural conditions for a long time. Any imbalance in nutrient use, when coupled with the use of high yield seeds, depletes the soil of naturally occurring minerals, and over time, the soil becomes infertile.

Another important drawback of high doses of chemical fertilisers is their effects on the

environment. Water soluble chemicals used as fertiliser leach away from the soil and contaminate both ground as well as surface water. High phosphate and nitrate levels in water lead to eutrophication. When excessive nutrients reach rivers and lakes, algae and other such aquatic plants use them to grow on the water surface. This increased plant growth uses up all the dissolved oxygen in water, in addition to acting as a physical barrier to atmospheric oxygen. In the absence of oxygen, all the aquatic life in the water, but below its surface (including fish and other organisms), start dying.

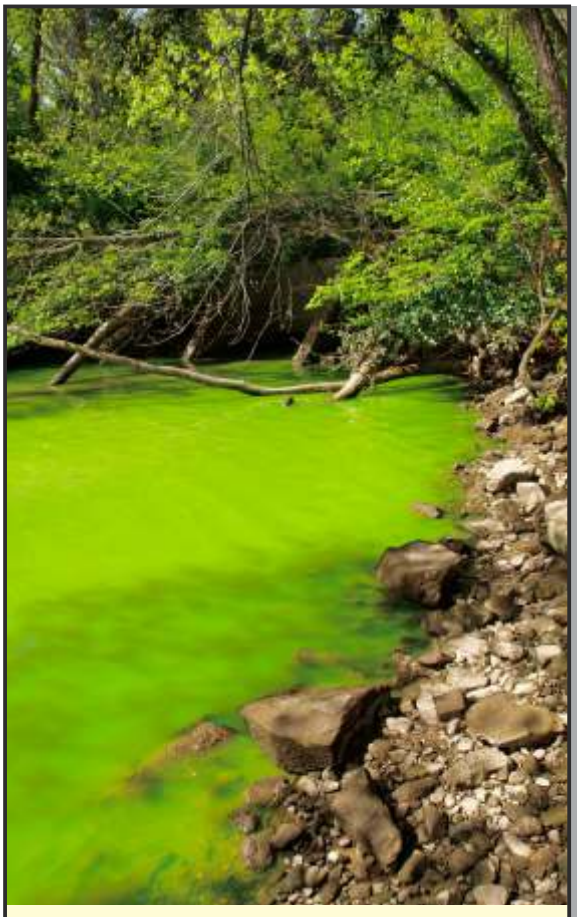

Fig. 3: Eutrophication due to high nutrient content in water *Photo: Alexandr Trubetskoy*

However, as natural/organic fertilisers alone cannot yield the quantity of food needed to make food available to more than a billion people of the country, only the judicious use of chemical fertilisers, along with naturally available soil conditioners can ensure long term food security.

Conclusion

After seeds, chemical fertilisers are some of the most important inputs in the agricultural sector today, especially in achieving the high yields of crop outputs needed to ensure our food security. Depending on the specific nutrient needs of their crops, a variety of fertilisers are used by farmers. Chemical fertilisers are produced by many small and large manufacturers, within the country. Some amounts of these fertilisers are also imported every year. This industry is closely monitored and controlled by the Government of India to ensure availability of fertilisers at affordable prices to farmers. The judicious use of chemical fertilisers, along with other natural fertilisers and soil conditioners, can ensure sustained agricultural production, as well as continued and adequate availability of food for all.

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Jayalekshmy Ayyer *is a postgraduate in Chemistry from IIT, Bombay and Ph.D. from the University of Chicago USA. She has worked as Scientist at IIT, Bombay and Indian Institute of Science, Bangalore prior to joining the fertiliser company Gujarat Narmada Valley Fertilisers & Chemicals Company Ltd. in 1986. She has been instrumental in setting up the company's R&D Centre and functioned as the Head of R&D Centre and Quality Control Department for several years.*

She is a Member of the American Chemical Society and has several research publications in National and International journals and several patents to her credit. Having keen interest in taking Science to the masses, she has been involved in the activities of Narmadanagar Community Science Centre. She can be contacted at jayayyer@yahoo.com